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Thermal Fatigue at Mixing Points in Industrial pipework

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Extended Abstract

Thermal fatigue has been affecting operations in many sectors, including the nuclear and the energy industries for many years, despite measures taken to mitigate it. A total of 13 failures have been reported in pressurized water reactors in nuclear power plants (NPP) resulting from thermal fatigue, occurring at different ages of the plants' usage [1]. Thermal fatigue has been understood as an aging problem, but damage such as a through-wall crack in Civaux 1, in France in 1998, occurred after only 1500h operation of the pressurized water reactor, necessitating more attention to the phenomenon [2] [3]. A piping section where two fluids (hot and cold) combine and converge downstream is named a mixing point (or T-junction). T-junctions are common in industrial plants where flow mixing is required, for instance, to locally dissipate heat. The turbulent mixing of the two fluids leads to thermal variation as a result of inhomogeneous mixing of the fluids which is predominant in the vicinity of the T- junction. This phenomenon is referred to as Thermal Striping [4]. During thermal striping, high-magnitude, low-frequency thermal and flow fluctuations propagate from the fluid down to the solid wall, inducing mechanical vibrations and local stresses in the pipe. If the stress variation is above the fatigue limit of the pipe material, this can lead to crack initiation and propagation over a number of cycles. (The fatigue limit refers to a stress value below which the material can undergo an infinite number of load cycles without leading to fatigue failure). The method of utilizing leak before failure as a check to prevent damage has not been completely effective, as an undetected leak could lead to disaster, as was the case of an accident at a gas plant in Pascagoula, Mississippi, in 2016 [5]. A better method of preventing failure is to ensure proper and adequate checks are carried out at a predetermined frequency. The objective of the research is to utilize computational fluid dynamics (CFD) and Finite Element Analysis (FEA) to understand the combined effect of constraint and temperature fluctuation at the vicinity of mixing points, and also to develop more effective inspection criteria to investigate T-junctions susceptible to thermal fatigue. The methodology proposed in this research involves experimental measurements and numerical simulations. The numerical methodology will involve Fluid Structure Interaction (FSI) analysis. This involves the use of CFD and FEA to determine the thermal fluctuation at the wall and the subsequent thermal stresses and strains. Model developments are ongoing to understand the phenomena taking place at pipe mixing points, while experiments will be used to validate the simulation results. The results of strain and stress obtained from FEA and experiments will be used to determine crack initiation and propagation, which will help to develop inspection criteria and frequency. The outcome of this research is to ensure improvement and optimisation in the cycle of inspections and maintenance around mixing points affected by thermal fatigue, in order to reduce costs, while ensuring integrity and operational safety.

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